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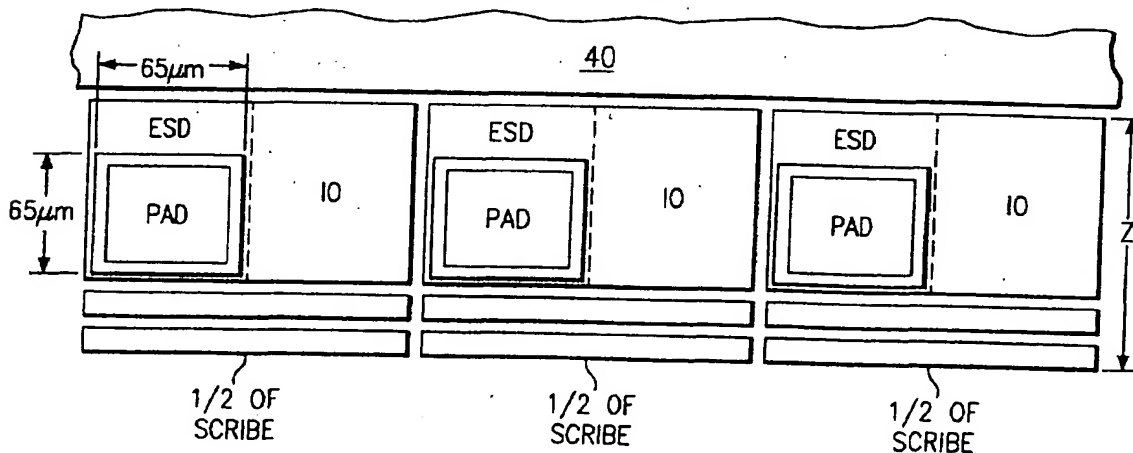
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(54) Input/output architecture for integrated circuits

(57) A described embodiment of the present invention includes an integrated circuit having a plurality of I/O modules. The I/O modules include a bond pad formed on a substrate. The I/O modules also include an electrostatic discharge device formed in the substrate. The electrostatic discharge device is at least partially formed

beneath the bond pad. The I/O module also includes an I/O buffer formed in the substrate. The I/O buffer is connected to the bond pad. The I/O buffer provides communication between the bond pad and circuitry formed in the substrate. The circuitry is positioned substantially adjacent to both the electrostatic discharge device and the I/O buffer.

FIG. 5



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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to the field of integrated circuit layout and design. More specifically, the present invention relates to a design process and structure for providing input/output components on an integrated circuit.

DESCRIPTION OF THE RELATED ART

[0002] The development of the technology for the fabrication and design of integrated circuits has allowed designers to place ever increasing functionality onto a smaller area of integrated circuits. This makes the surface area of an integrated circuit extremely valuable. A component of integrated circuits that occupies a relatively large area are the input/output (I/O) modules.

[0003] I/O Modules provide the attachment point for electrical bonding to the integrated circuit die. I/O modules generally consist of a bond pad, an electrostatic discharge protection device and I/O buffer circuitry. The core circuitry is generally composed of very small devices. These devices are fast and densely packed, but fragile. The I/O modules provide protection to the core circuitry as well as a connection point for getting signals on and off of the integrated circuit. Because they must provide this protection function, I/O modules use relatively large devices and occupy a disproportionate area on the integrated circuit die.

[0004] I/O modules are generally positioned on the periphery of the integrated circuit die. This makes the process of bonding to the bond pads easier and helps buffer the core circuitry from the physical stresses of cutting the die from the semiconductor wafer during manufacturing. The area occupied by the I/O modules is determined by the height (distance from the edge of the die to interior edge of the I/O modules) of the I/O modules. The remaining portion of the chip is available for core circuitry. Designers are always looking for ways to put more functionality onto an integrated circuit. Because of this, it is desirable to use the minimum area necessary for I/O modules to provide as much area as possible for the core circuitry.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention provides a structure and method allowing integrated circuit elements to be positioned efficiently.

[0006] The present invention minimizes the area necessary for the I/O periphery in an integrated circuit.

[0007] These and other objects are provided by a described exemplary embodiment of the present invention, which includes an integrated circuit having a plurality of I/O modules. The I/O modules include a bond pad formed on a substrate. The I/O modules also in-

clude an electrostatic discharge device formed in the substrate. The electrostatic discharge device is at least partially formed beneath the bond pad. The I/O module also includes an I/O buffer formed in the substrate. The I/O buffer is connected to the bond pad. The I/O buffer provides communication between the bond pad and circuitry formed in the substrate. The circuitry is positioned substantially adjacent to both the electrostatic discharge device and the I/O buffer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a more complete understanding of the present invention and the advantages thereof, reference should be made to the following Detailed Description taken in connection with the accompanying drawings in which:

Figure 1 is a layout diagram of a prior art I/O module; Figure 2 is a layout diagram of the I/O module of Figure 1 positioned on an integrated circuit die; Figure 3 is a layout diagram showing a plurality of prior art I/O modules positioned next to a functional core;

Figure 4 is a layout diagram of an embodiment of the present invention;

Figure 5 is a layout diagram another embodiment of the present invention in which a plurality of I/O modules positioned by a functional core;

Figure 6 is a chart showing the die area recovered using the described embodiments of the present invention;

Figure 7 is a detailed layout diagram of the embodiment of Figure 4 and

Figure 8 is a schematic diagram of an output circuit suitable for used with the described embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0009] Figure 1 is a layout diagram of a prior art I/O module. I/O module 10 includes a bond pad 12, electrostatic discharge (ESD) device 14 and I/O buffer 16. Also included in Figure 1 are scribe area 20 and scribe seal 22. Scribe area 20 provides space for the saw that separates a wafer into die. Scribe seal 22 is a physical buffer area between the dice and the scribe area. Scribe seal allows for the dissipation of physical stress during the dicing process.

[0010] The components of I/O module 10 are laid out in the conventional manner with the bond pad and the edge of the integrated circuit die and the I/O buffer 16 positioned between the functional core 40 and bond pad 12. I/O module 10 is an advanced module in that ESD device 14 is positioned beside bond pad 12.

[0011] Figure 2 is a layout diagram showing the position of I/O modules 10 on die 30 in I/O region 32. Func-

tional core 40 is surrounded by I/O region 32. The overall size of the die 30 is determined by the width of core 40 (X) plus twice the height of the I/O modules 10 times the length of core 40 (Y) plus twice the height of the I/O modules 10. The formula for the area is

$$\text{Area} = (X+2H)*(Y+2H)$$

which can be written as

$$\text{Area} = XY+2HY+2HX +4H^2.$$

As can be seen, from the above formula, the height of the I/O modules 10 has a large impact on the overall area of the die 30. Although Figure 2 includes fourteen I/O modules 10, it is more common for an integrated circuit to include from 64 to 300 I/O modules. Figure 3 is an enlarged portion of the layout of Figure 2 showing four I/O modules 10 and their position relative to functional core 40.

[0012] Figure 4 is a layout diagram of a novel I/O module 100, which is structured according to the teachings of the present invention. I/O module 100 is preferably formed on a crystalline semiconductor substrate. Bond pad 112 is positioned adjacent to scribe seal 122 as in the I/O module 10 of Figure 1. Bond pad 112 is preferably formed of an aluminum composite layer, copper layer or gold clad copper layer having conductive upper surface for ball bonding. I/O buffer 116 is a similar I/O buffer circuit with a similar layout to that of I/O buffer 16. However, because I/O buffer 116 is positioned adjacent to scribe seal 122, the overall height Z of I/O module 100 is the height of I/O buffer 116 plus the width of scribe seal 122 and one half of scribe line 120.

[0013] In contrast, the height H of prior art I/O Module is height of I/O buffer 16 plus the height of ESD device 14 plus the width of scribe seal 22 and one half of scribe line 20. For example, the height of I/O buffer 16 may be 71 μ m, the height of ESD device 14 may be 21 μ m, the height of bond pad 12 may be 50 μ m and the combined height of the scribe seal 22, scribe line 20 and additional spacing may be 46 μ m. This provides an overall height H of 188 μ m.

[0014] The inventive I/O module 100, however, provides a much smaller height Z using the same design rules. With the same dimensions for components of I/O module 10, I/O module 100 has a height of 81 μ m for I/O module 116 plus 46 μ m for scribe line 120 and scribe seal 122. By careful layout of I/O module 116, its height can be reduced to 74 μ m, thus providing an overall height Z of 120 μ m.

[0015] Figure 5 shows I/O modules 100 as positioned adjacent to functional core 40. Functional core 40 may be any function capable of being implemented with integrated circuitry. For example, functional core 40 may comprise an application specific integrated circuit or a

digital signal processor. Preferably, the circuitry of functional core 40 is fabricated using CMOS or BiCMOS processes. Because I/O modules 100 are wider than corresponding prior art modules, fewer I/O modules 100 can be provided for a given size of functional core 40. However, integrated circuit designs are rarely constrained by the number of I/O buffers. More often, the number of input/output connections is limited by the package. Packages that provide more than 200 connection points (for advanced ball grid arrays) can be cost prohibitive. Therefore, I/O modules 100 significantly reduce the die size for a given functionality without constraining the operational characteristics of the integrated circuit. Conversely, I/O modules 100 allow for a larger functional core for a given die size.

[0016] Figure 6 is a chart comparing the die size and wasted area using the prior art I/O module. Six functional core sizes are listed. For each core size, a prior art I/O module with height H is listed and a corresponding novel module with the height Z is listed. Also listed is the total area using each module, the maximum number of I/O modules that can be placed on the die, the wasted area and the percentage of area wasted using the prior art. As can be seen from Figure 6, the novel I/O module 100 reduces wasted space by 6%-13%, depending on functional core size.

[0017] Figure 7 is a layout diagram showing the specific topographical features of I/O module 100. ESD device 114 can be any number of electrostatic discharge devices. Examples of suitable devices can be found in Chen et al., U.S. Patent No. 5,982,217, which is assigned to the assignee of this application and which is incorporated herein by reference.

[0018] I/O buffer 116 can be any number of known designs for providing input and output drivers. An example is shown in Figure 8. I/O buffer 116 is preferably fabricated using a multi-level metal system and a device fabrication process such as that shown in Smayling et al., U.S. Patent No. 5,767,551, which is assigned to the assignee of this application and which is hereby incorporated by reference. I/O buffer 116 is a three stage, complementary output buffer designed for high speed and to provide a well conditioned output signal.

[0019] The input signal on input A of I/O buffer 116 is inverted by transistor 202 and a push-pull inverter formed by transistors 204 and 206. Transistor 208 prevents saturation of transistor 206 for high speed operation. The output from transistors 204 and 206 is inverted again by transistors 210 and 212 with a pull up (when appropriate) from transistor 214. The drain of transistor 214 is connected to the high V_{DD} voltage supply (symbolized by a circle). The output from transistors 204 and 206 also drives the push-pull inverter formed by transistors 216 and 218. The output from transistors 210 and 212 drives the gate of drive transistor 220. The output from transistors 216 and 218 drives the gate of drive transistor 222. The output from transistors 210 and 212 also drives the gate of pull-up transistor 224.

[0020] The inverse of input A, A' is applied to the gates of transistors 226, 228 and 230. Transistors 226, 228, 230, 232, 234, 236, 238, 240, 242 and 244 provide the same functions as transistors 202, 204, 206, 208, 214, 210, 212, 216, 218, and 224, respectively. Additionally, transistors 245 and 248 invert and delay the output of transistors 236 and 238. In addition, transistors 250 and 252 invert and delay the output of transistors 240 and 242. The output of transistors 236 and 238 drives the gate of output transistor 254. The output of transistors 250 and 252 are used to drive the gate of output transistor 256.

[0021] Transistors 258, 260, 262, 264 and 266 constitute a pull down AND gate driving output transistor 278. Transistors 268, 270, 272, 274 and 276 constitute a pull-down AND gate driving output transistor 280. The pull-down portions of the gates are voltage limited by transistors 262 and 272 in that are gate strapped to V_{DD} (the lower voltage supply symbolized by a horizontal line). This prevents saturation of transistors 278 and 280. The parallel pull-up transistors 258, 260, 268 and 270 provide rapid shut off of transistors 278 and 280. The gate inputs of transistors 258-270 are timed to provide staggered gate charging or draining capacity and to avoid race conditions where all transistors in a series are on.

[0022] Transistors 282-290 provide a complementary pull-up function for output transistors 298 and 300 to the function provided by transistors 258-270 for output transistors 278 and 280. In summary, transistors 220, 222, 254 and 256 provide rapid medium drive signals to begin and signal transition. Transistors 278, 280, 298 and 300 provide high capacity drive with gate drive signals that are carefully controlled. I/O buffer 116 in Figure 8 is an output buffer of a certain preferred structure. However, the structure of Figure 8 in no way limits the intended scope of the invention. The invention contemplates the use of any input or output buffer.

[0023] Although specific embodiments of the present invention are described herein, they are not to be construed as limiting the scope of the invention. For example, although specific circuits and device fabrication techniques are described and referred to herein, many specific devices and fabrication techniques may be advantageously used within the scope of the invention. Many embodiments of the invention will become apparent to those skilled in the art in light of the teachings of this specification.

Claims

1. An integrated circuit having a plurality of I/O modules comprising:

a bond pad formed on a substrate;
an electrostatic discharge device formed in the substrate, the electrostatic discharge device

being at least partially formed beneath the bond pad;

an I/O buffer formed in the substrate and connected to the bond pad, the I/O buffer providing communication between the bond pad and circuitry formed in the substrate, wherein the circuitry is positioned substantially adjacent to both the electrostatic discharge device and the I/O buffer.

2. An integrated circuit comprising:

a functional core formed on a substrate, the functional core being positioned centrally on the substrate; and
an I/O region positioned at the periphery of the functional core, the I/O region including a plurality of I/O modules, the I/O modules including:

a bond pad formed on a substrate;
an electrostatic discharge device; and
an I/O buffer wherein the I/O buffer is not positioned between the bond pad and the functional core.

3. The integrated circuit of Claims 1 or 2, wherein the substrate is a silicon substrate.
4. The integrated circuit of any preceding Claim wherein the I/O buffer is an output buffer.
5. The integrated circuit of any of Claims 1 to 3 wherein the I/O buffer is an input buffer.
6. The integrated circuit of any of Claims 1 to 3 wherein the I/O buffer is a complementary output buffer.
7. The integrated circuit of any of the preceding claims wherein the circuitry is CMOS circuitry.
8. The integrated circuit of any of Claims 1-6, wherein the circuitry is BICMOS circuitry.
9. The integrated circuit of any of the preceding claims, wherein the circuitry is an application specific integrated circuit.
10. The integrated circuit of any of the preceding claims, wherein the circuitry is comprised in a digital signal processor.
11. The integrated circuit of any of the preceding claims, wherein substantially the entire surface of the substrate beneath the bond pad is occupied by the electrostatic discharge device.
12. The integrated circuit of Claims 2 to 11, wherein the functional core is comprised in an application spe-

cific integrated circuit.

13. The integrated circuit of Claims 2 to 11, wherein the functional core is comprised in a digital signal processor.

14. An integrated circuit comprising:

a functional core formed on a substrate, the functional core including a plurality of integrated circuit elements and being positioned centrally on the substrate; and
an I/O region positioned at the periphery of the functional core, the I/O region including a plurality of I/O modules, the I/O modules including:

a bond pad formed on a substrate, the bond pad including a conductive surface for providing electrical connection to external devices;
an electrostatic discharge device formed beneath the bond pad; and
a CMOS I/O buffer wherein the I/O buffer is not positioned between the bond pad and the functional core.

15. A method for forming an integrated circuit having a plurality of I/O modules comprising:

forming a bond pad formed on a substrate;
forming an electrostatic discharge device formed in the substrate, the electrostatic discharge device being at least partially formed beneath the bond pad; and
forming an I/O buffer formed in the substrate and connected to the bond pad, the I/O buffer providing communication between the bond pad and circuitry formed in the substrate, wherein the circuitry is positioned substantially adjacent to both the electrostatic discharge device and the I/O buffer.

16. A method for forming an integrated circuit comprising:

providing a functional core formed on a substrate, the functional core being positioned centrally on the substrate; and
in an I/O region positioned at the periphery of the functional core, forming a plurality of I/O modules, the steps for forming the I/O modules including:

forming a bond pad formed on a substrate;
forming an electrostatic discharge device;
and
forming an I/O buffer wherein the I/O buffer is

not positioned between the bond pad and the functional core.

17. The method of Claims 15 or 16 wherein the substrate is a silicon substrate.

18. The method of Claims 15 or 16 wherein the I/O buffer is an output buffer.

19. The method of Claims 15 or 16 wherein the I/O buffer is an input buffer.

20. The method of Claims 15 or 16 wherein the I/O buffer is a complementary output buffer.

21. The method of any one of Claims 15-20 wherein the circuitry is CMOS circuitry.

22. The method of any one of Claims 15-20 wherein the circuitry is BICMOS circuitry.

23. The method of any one of Claims 15-22 wherein the circuitry is an application specific integrated circuit.

24. The method of any one of Claims 15-23 wherein the circuitry is digital signal processor.

25. The method of any one of claims 15-24 wherein the entire surface of the substrate beneath the bond pad is occupied by the electrostatic discharge device.

26. The method of Claim 16 wherein the functional core is an application specific integrated circuit.

27. The method of Claim 16 wherein the functional core is digital signal processor.

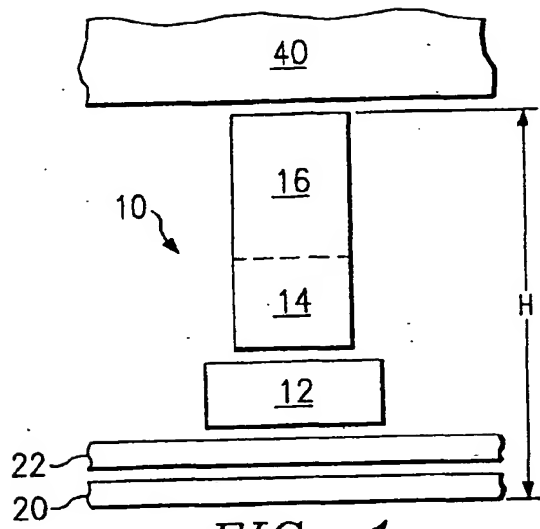


FIG. 1
(PRIOR ART)

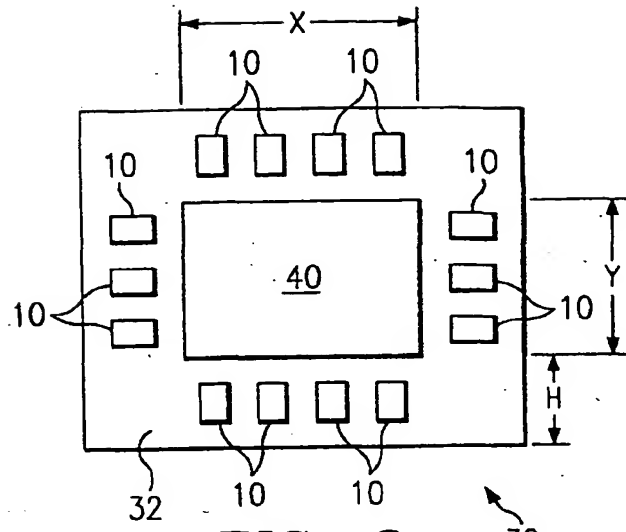


FIG. 2
(PRIOR ART)

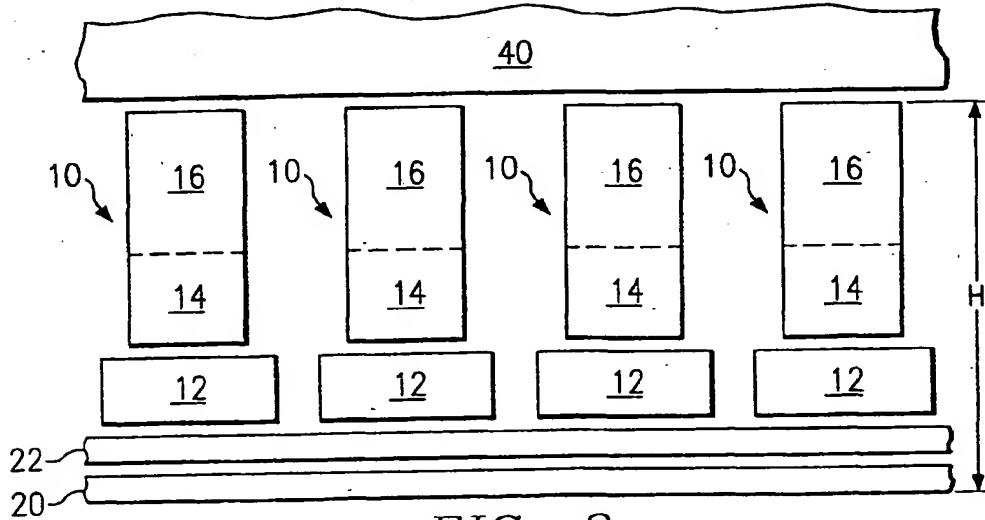


FIG. 3
(PRIOR ART)

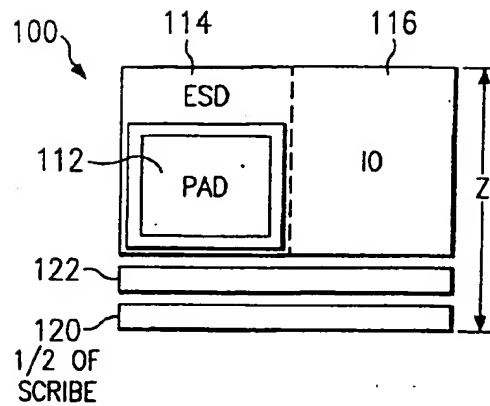


FIG. 4

FIG. 5

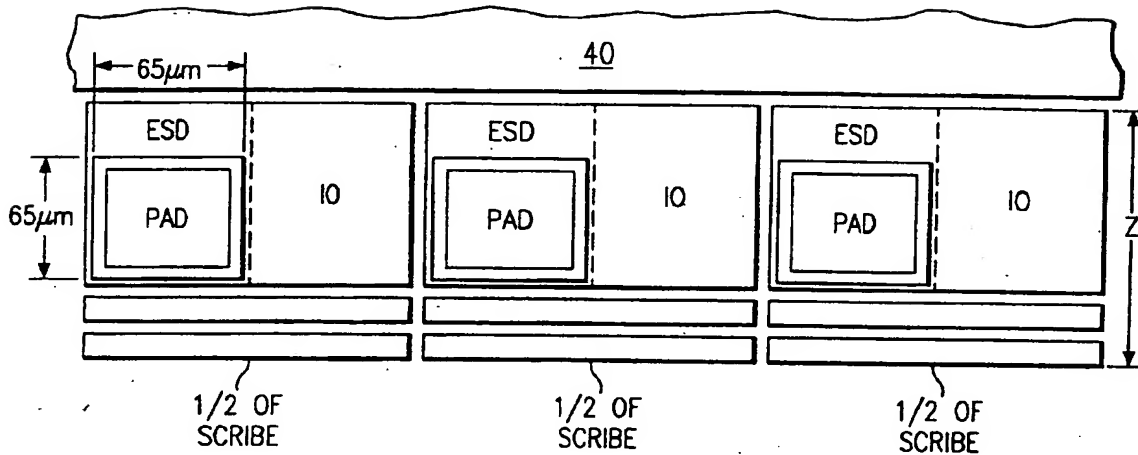
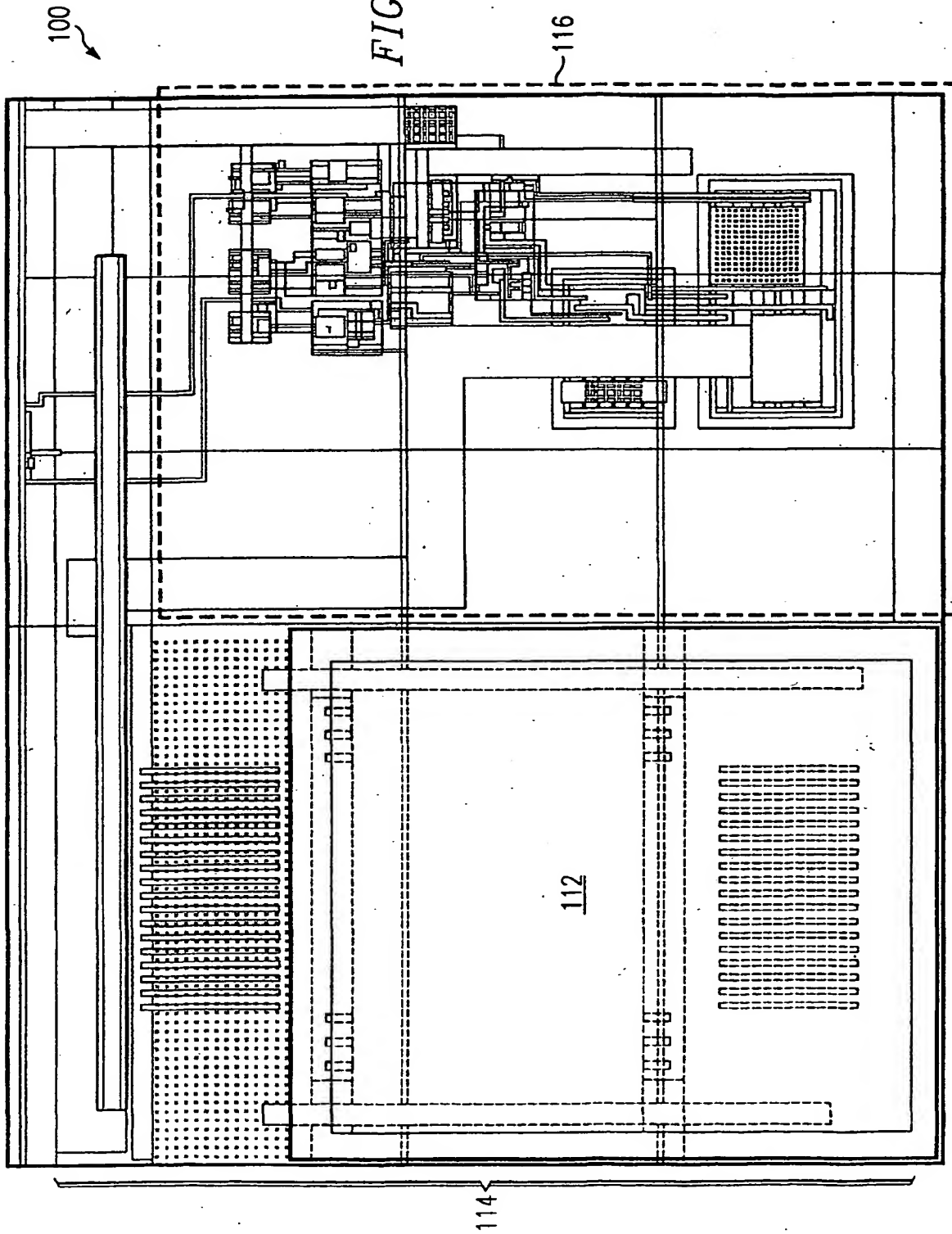


FIG. 6

CORE AREA, mm ²	mm/SIDE	IO HEIGHT, μm	IO WIDTH, μm	AREA	MAX IO	WASTED AREA	% OF CORE
10	3.162278	H=188	75	12.51941	169	1.67	13%
		Z=120	108	11.57549	117		
20	4.472136	H=188	75	23.50442	239	2.33	10%
		Z=120	108	22.20423	166		
30	5.477226	H=188	75	34.26025	292	2.83	8%
		Z=120	108	32.68667	203		
40	6.324555	H=188	75	44.89744	337	3.26	7%
		Z=120	108	43.09339	234		
50	7.071068	H=188	75	55.45882	377	3.63	7%
		Z=120	108	53.45171	262		
60	7.745967	H=188	75	65.96634	413	3.97	6%
		Z=120	108	63.77566	287		

FIG. 7



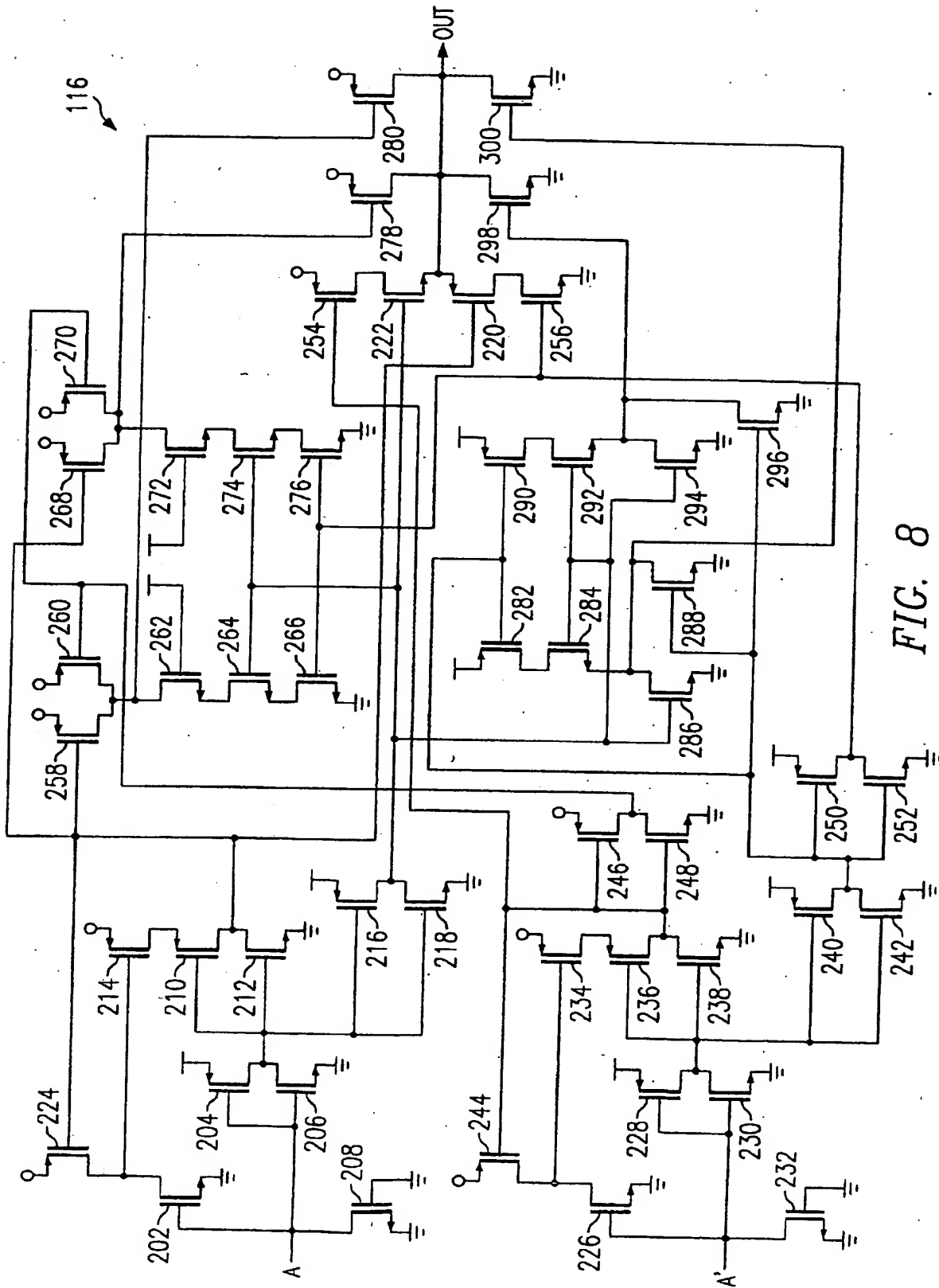


FIG. 8

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